

Studies of the Vector Field in Shallow Water and in the Presence of 3-D Variability

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LONG-TERM GOALS

The goals of this work were multi-faceted, consistent with the various efforts covered by this project. In all cases, however, the focus was on the study of the flow of energy in the acoustic field. One goal was to examine the information that is available from point measurements of the directional noise field, and potential applications of this data for geoacoustic inversion. Another goal was to improve our understanding of the significance of 3-D propagation effects and quantify their relative importance in areas of interest. Particular focus was placed on propagation in littoral regions and in continental shelf canyons.

OBJECTIVES

The overall objective of this work was to improve our understanding of various features in the acoustic vector field, including noise variability in shallow water and the influence of three-dimensional environmental variability on the propagation of acoustic energy.

WORK COMPLETED

This work continued and expanded upon previous efforts to study the effects of environmental variability on the 3-D structure of the total acoustic field (pressure, particle velocity, acoustic intensity, etc). In FY12, the formal equations for computing 3-D scattering from 2-D rough surfaces were developed. Implementation of these expressions and model validation was the focus of much of the FY13-14 work. In addition, the typical approach used to model the density discontinuity at the seafloor was revisited in FY14-15. Higher order approximations and hybrid approaches between split-step Fourier and finite-difference schemes were considered.

In FY15, the focus of the modeling effort was to improve the accuracy and efficiency of the 3-D MMPE model. This included adaptations of the code to improve the bottom interface treatment, and a complete rewrite of the code in an upgraded version of Fortran that can be utilized on multi-processor high-performance computer systems.

In order to investigate the ability to utilize point measurements of the directional noise field for potential applications of geoacoustic inversion, simple noise models were developed to represent data that would be measured on an acoustic vector sensor. Basic processing schemes were then evaluated to determine if such data could yield information on the directional nature of the ambient noise. In addition, data collection events were conducted in FY15 with acoustic vector sensors to provide some test data sets. This allowed some processing strings to be developed.

RESULTS

3-D MMPE Modeling:

In FY15, the primary goal was to improve the accuracy and efficiency of the 3-D MMPE model. Accuracy improvements were achieved by adapting the finite element bottom density discontinuity treatment previously developed by Yevick and Thomson (1997). These results are described below. Improvements in efficiency were realized by rewriting the code in an updated version of Fortran, including adaptation of the code for use on multi-processor machines. This was recently completed, and results are identical to previous versions, indicating proper implementation of the updated code. This code is now being used on NPS high performance computer systems to investigate 3-D environmental effects on propagation. Results are forth-coming in the near future.

Bottom Density Discontinuity Treatment:

Continuing efforts initiated in FY14, a collaboration with Dave Thomson (Canada) investigated the treatment of the bottom density discontinuity in PE models, including various smoothing approaches as well as extensions of the hybrid split-step Fourier/finite-difference (SSF/FD). Results of various SSF and SSF/FD model implementations were investigated in a simple Pekeris waveguide of depth 300m out to a maximum range of 20km. Solutions were compared with the Couple97 normal mode model. It was found that proper sampling and parameter specification improved the results of all models.

However, the hybrid SSF/FD approach was found to substantially improve the accumulated phase error issue, known to be a problem in SSF algorithms in shallow water. Figure 1 displays results of TL traces at a depth of 100m for a 100Hz source transmitting at a depth of 180m for the normal mode model and various implementation of SSF or SSF/FD PE. The improvement in the phase accuracy at long range is clearly seen. This led to a general upgrade for all MMPE model versions.

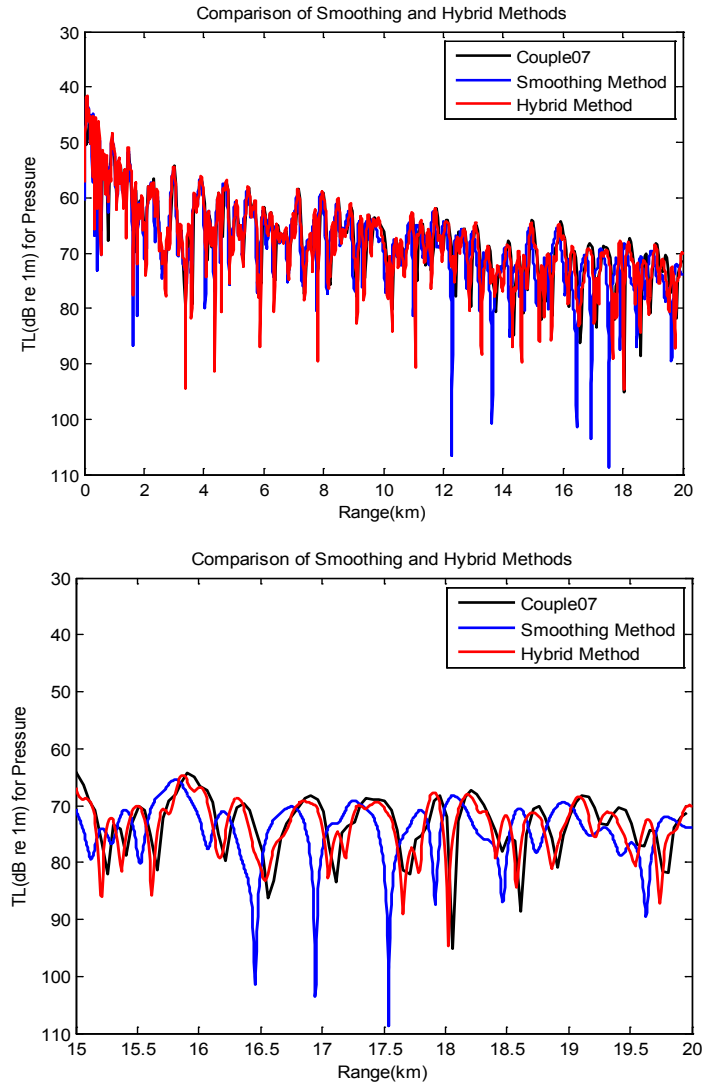


Figure 1: MMPE test case results for a simply Pekeris waveguide – comparison between benchmark solution (generated by Couple07), standard MMPE density smoothing approach, and hybrid SSF/FE treatment of bottom density. Upper panel displays full 20km range of calculation, which exhibits good agreement at short range but growing phase mismatch at longer range. Lower panel displays close-up of last 5km, which exhibits significant improvement of hybrid method over standard smoothing approach.

Point Measurements of Directional Noise:

For this problem, a basic algorithm was developed that evaluated time averages of the linear, coherent (cardioid) processing of a single vector sensor in the presence of ambient noise. A simple code was developed to create an azimuthally isotropic noise field with vertical directionality. An example is provided in Fig. 2, in which the background directionality is modeled with a noise notch near horizontal. A random noise field was then generated for pressure and three components of particle velocity. The lower left panel in the figure displays the vertical amplitude created from cardioid processing of the data as a function of time. Any given instant of time does not reveal the background shading. However, time averaging of the amplitude does produce a vertical structure consistent with

the background. This suggests such simple analysis of measured data has the potential to reveal structure in the ambient noise field.

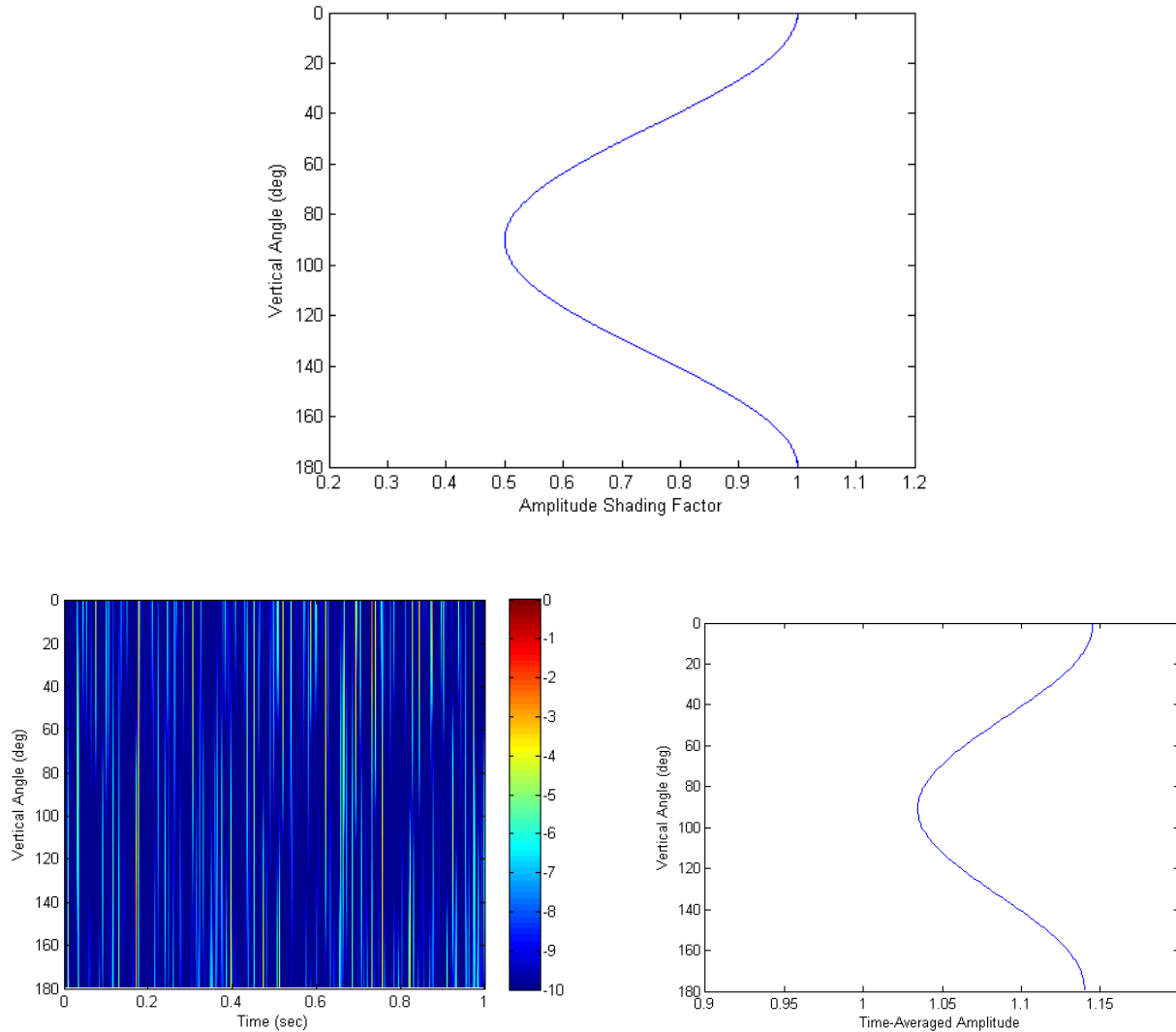


Figure 2: Simulated effects of vertical noise directionality on vector sensor processing. Random noise field was generated with vertical directionality defined by shading function (upper panel). Standard linear processing of simulated vector sensor data shows random fluctuations in vertical arrival structure (lower left panel), but a time average reveals directionality of underlying noise field (lower right panel).

Data was collected on a pair of underwater acoustic vector sensors in Monterey Bay in FY15, and preliminary analysis has begun. However, the data collected did not coincide with periods of good ambient noise; nearby interferers will likely distort the directionality calculations. Additional data collection events are planned near the end of the year.

IMPACT/APPLICATIONS

The impact of the work done on improving the accuracy and efficiency of the 3-D model is to allow researchers to directly compute the 3-D, out-of-plane scattering effects of the environment. This could be applied to the investigation of acoustic communication algorithms, a study of the effects on high-frequency sonar systems, or an investigation of potential focusing effects due to canyons. In addition, 2-D calculations have also been improved, most notably for broadband calculations. In each case, the corresponding acoustic vector field is computed for more advanced processing predictions.

The studies of the directionality obtained from the ambient noise field provide a foundation for future efforts to extract geoacoustic information from pointwise measurements of the acoustic field. This could lead to very efficient environmental characterization from relatively simple platforms.

RELATED PROJECTS

The work done with MMPE to improve the modeling of 3-D propagation and scattering effects, in both the acoustic pressure and velocity fields, is supporting an on-going effort with Dr. George Dossot and colleagues at the Naval Undersea Warfare Center Division Newport. The work done on improving the treatment of the bottom density discontinuity was a collaborative effort with Dr. David J. Thomson in Canada. Elements of this work are anticipated to continue in FY16.

PUBLICATIONS

Moss, G. and Smith, K.B., "Finite element simulation of the air-water interface," Proc. 22nd Int. Congress on Sound and Vibration, 12-16 July 2015, Florence, Italy. (Invited paper.)

Savas Erdim, "An Examination of Higher-Order Treatments of Boundary Conditions in Split-Step Fourier Parabolic Equation Models," M.S. Engineering Acoustics (Thesis), June, 2015.